



IT'S GUST ABOUT TIME:

*Harnessing the Wind for
Our Future Energy Needs*

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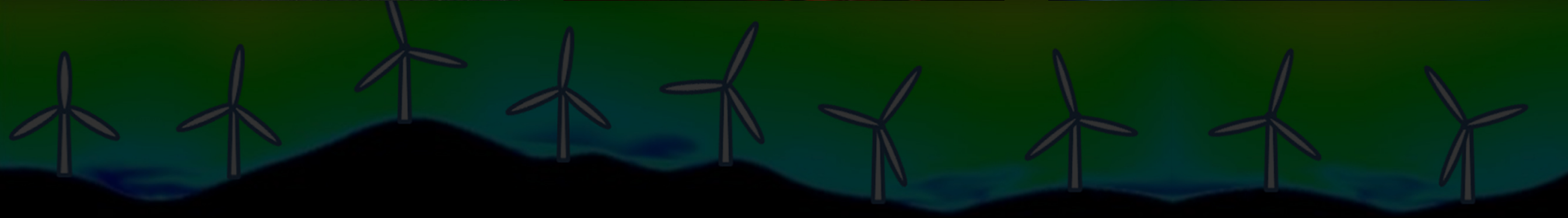
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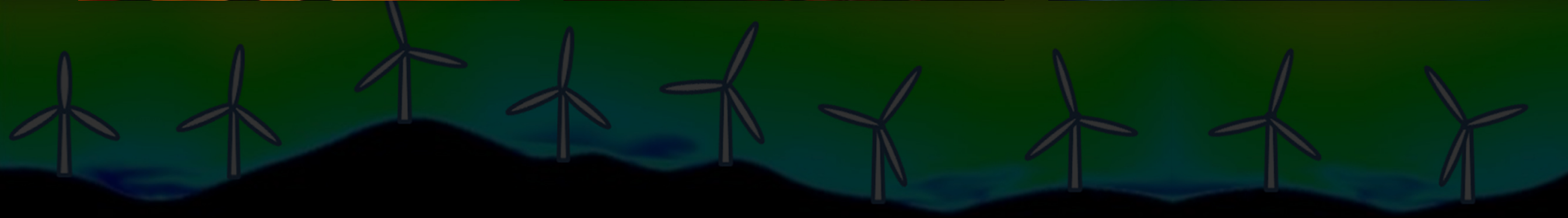
SCIENCE ON SATURDAY



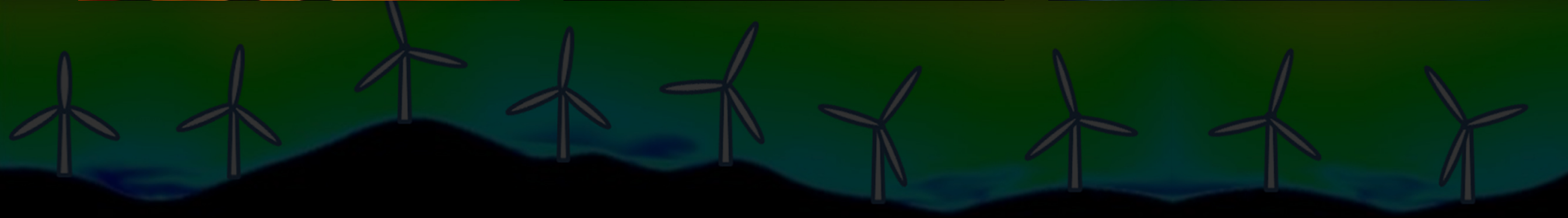
**Most of the energy we use today
is produced from fossil fuels**



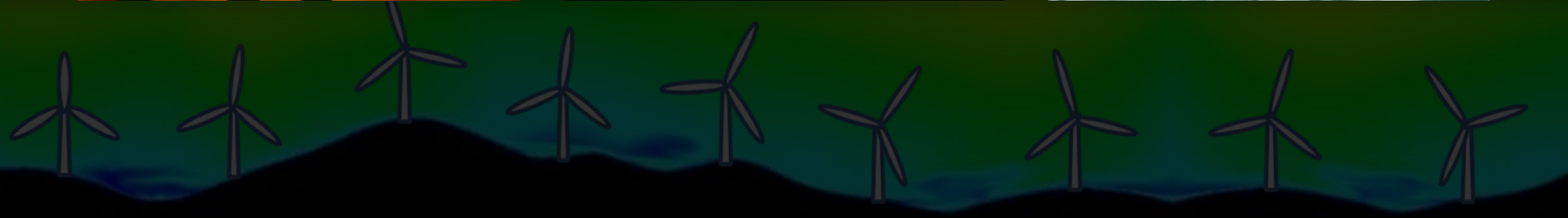
The burning of fossil fuels releases CO_2 into the atmosphere



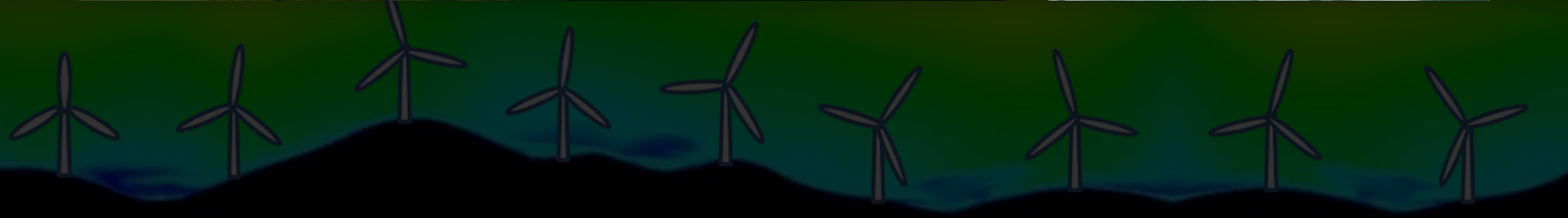
Increased atmospheric CO₂ may be changing the climate



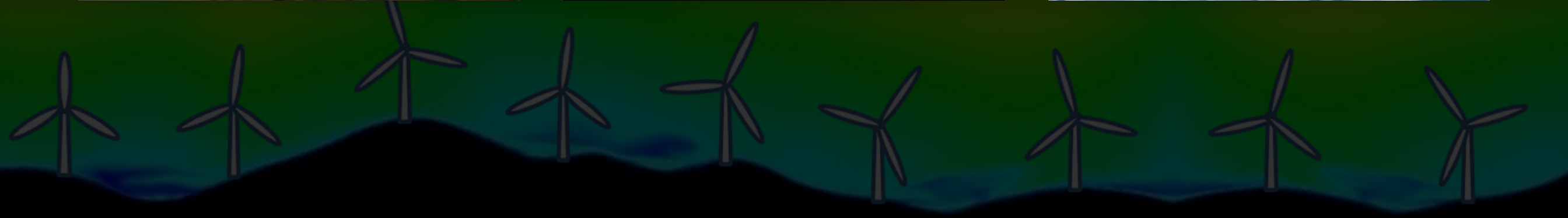
How will we satisfy humanity's energy needs in the future?



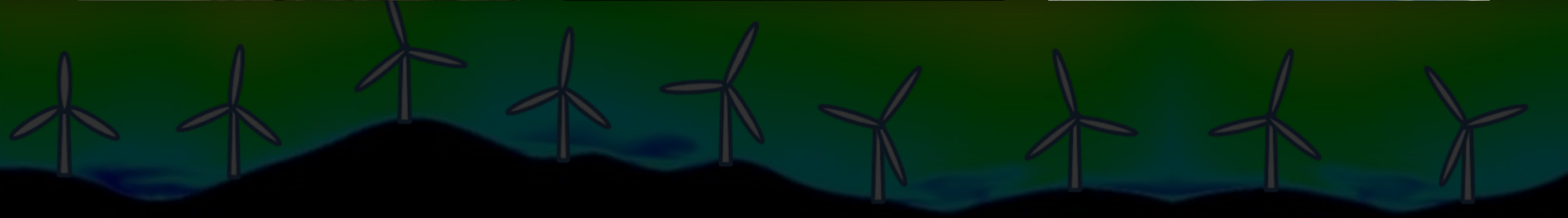
Green, renewable sources will satisfy humanity's energy needs in the future



Green, renewable sources will satisfy humanity's energy needs in the future



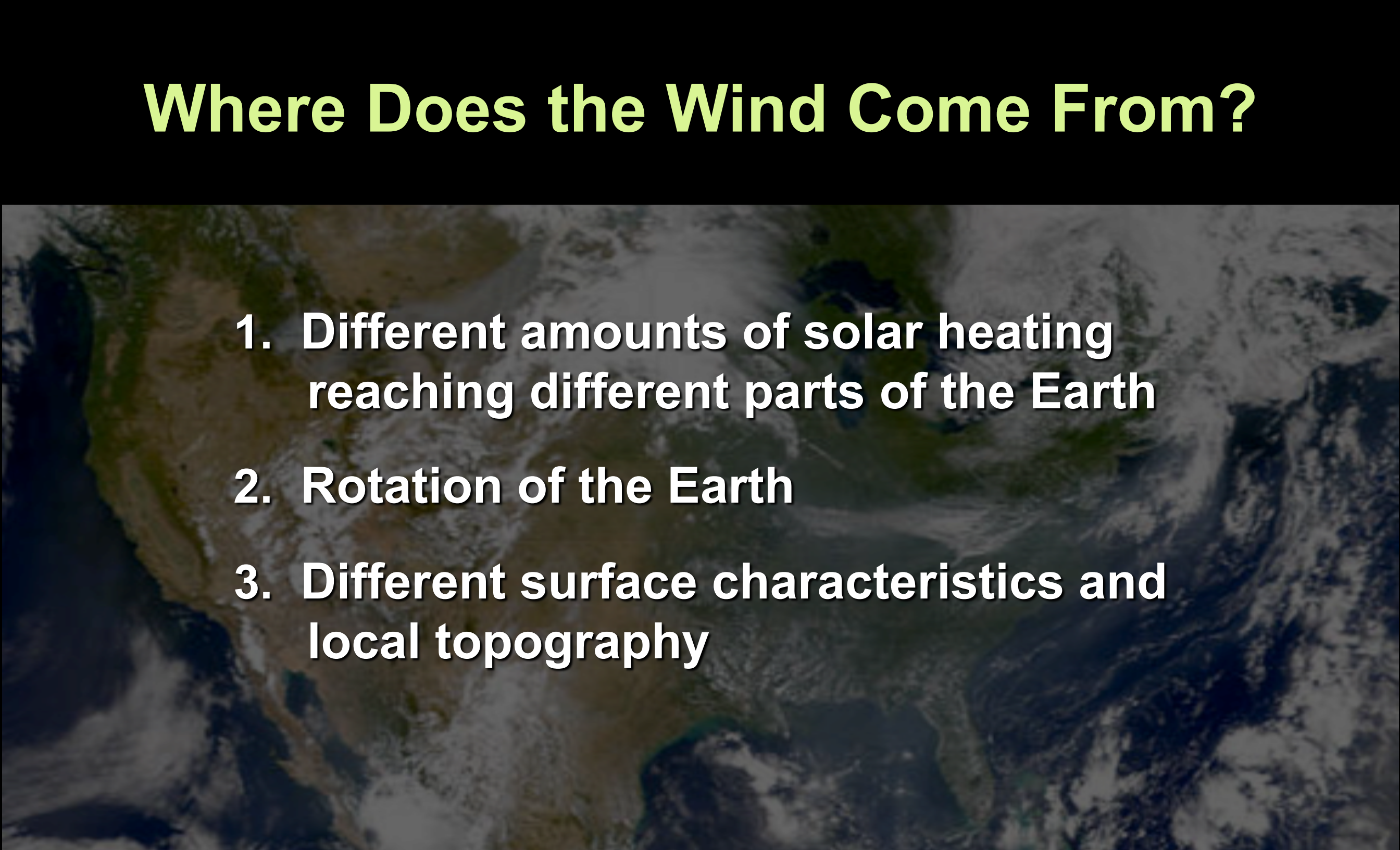
Green, renewable sources will satisfy humanity's energy needs in the future



Four Basic Wind Energy Concepts:

1. **Why the wind blows**
2. **How modern wind turbines harness the wind**
3. **The roles of science and engineering in improving wind energy capture**
4. **What challenges remain for you to solve?**

Where Does the Wind Come From?

- 
- A satellite image of Earth, showing a large portion of the Western Hemisphere. The image is darkened to serve as a background for the text. It shows the Americas, Europe, and parts of Africa and Asia, with prominent cloud formations over the oceans and some landmasses.
1. Different amounts of solar heating reaching different parts of the Earth
 2. Rotation of the Earth
 3. Different surface characteristics and local topography

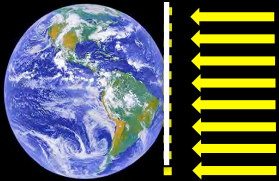
1. Solar Radiation: Most of Earth's energy comes from the sun

Watt (W) = flow of energy

Joule (J) = unit of
energy

$$W/m^2 = (J/s)/m^2$$

1336 Wm²

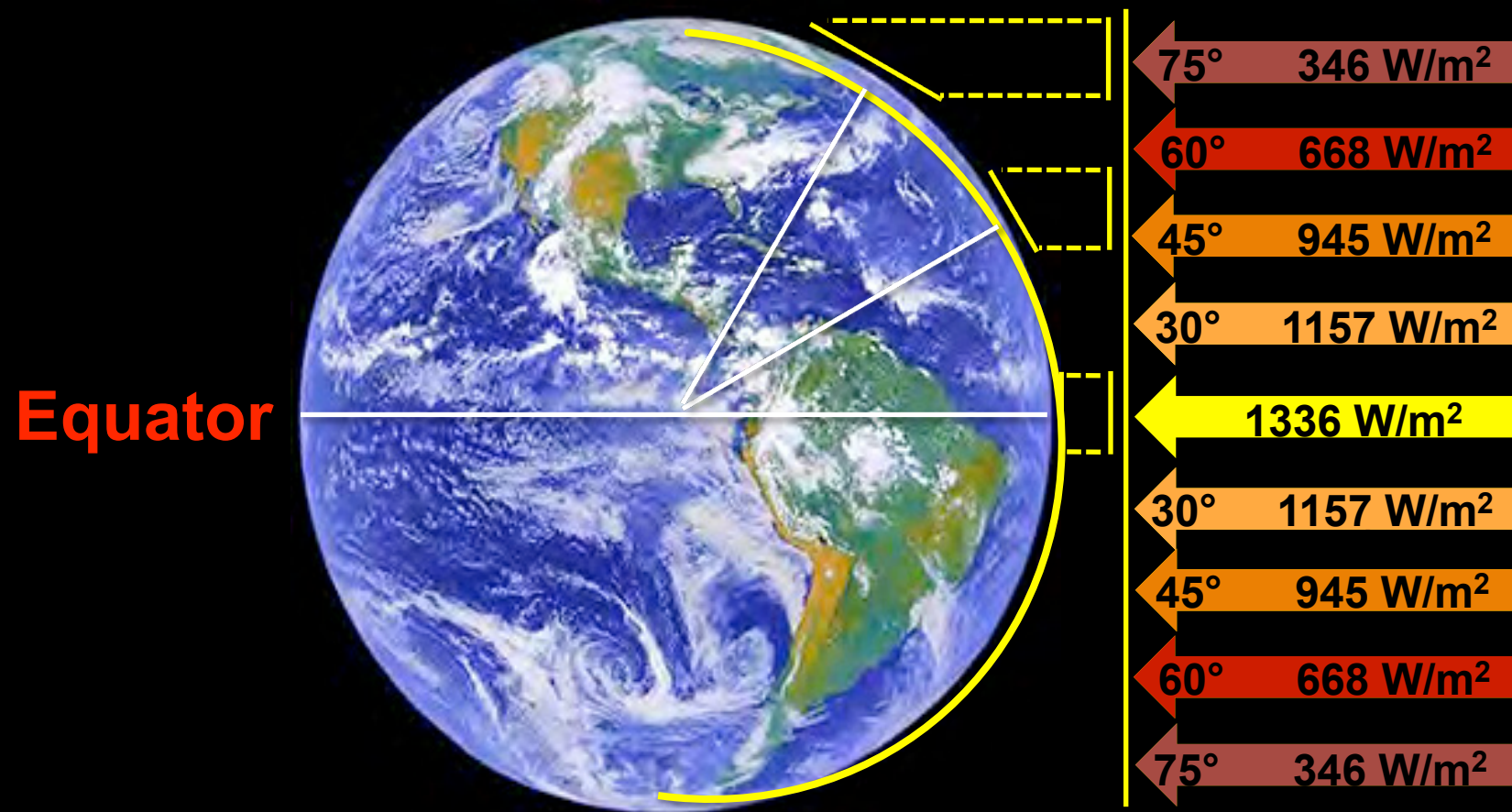


Solar
radiation
travels
radially
outward
from the
Sun

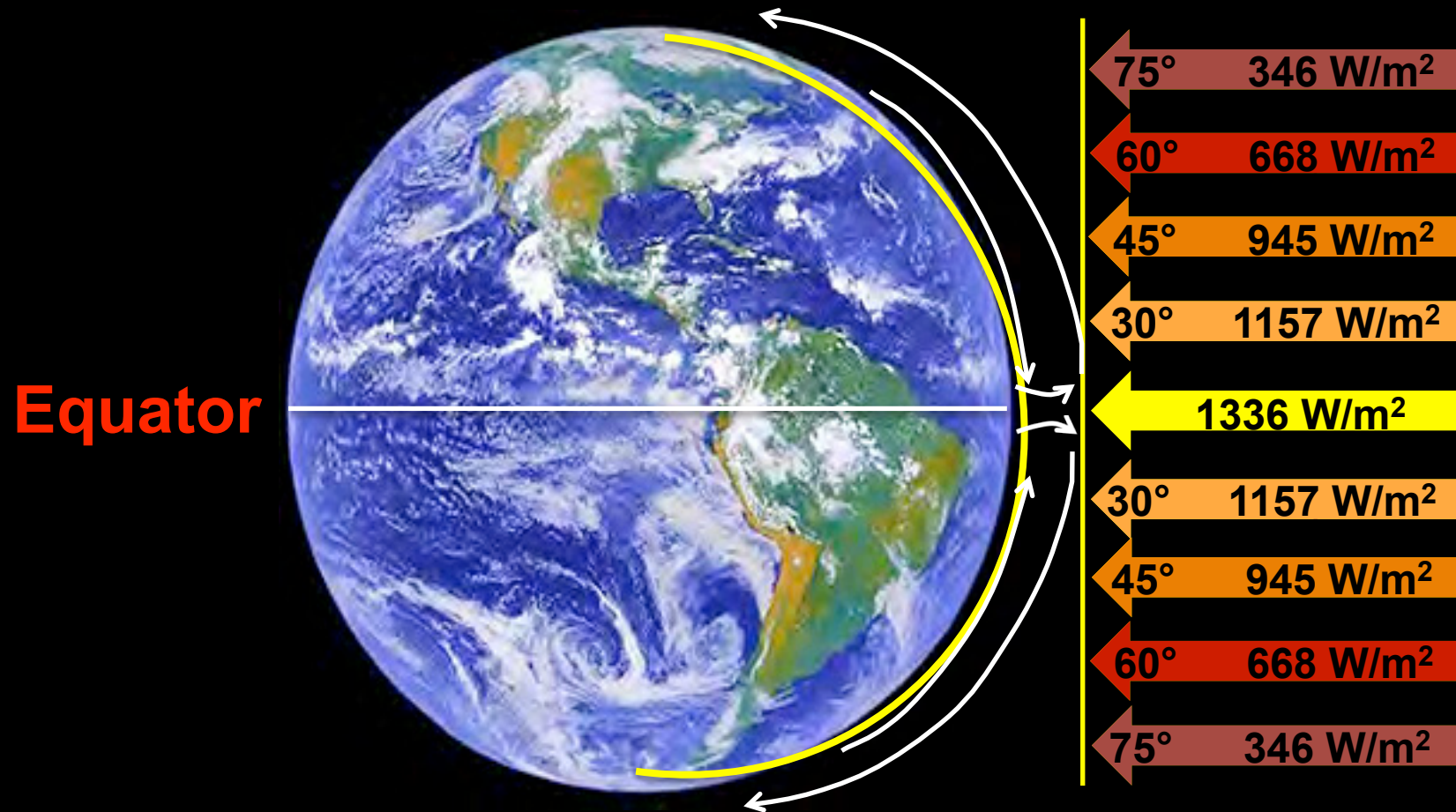
Su
n



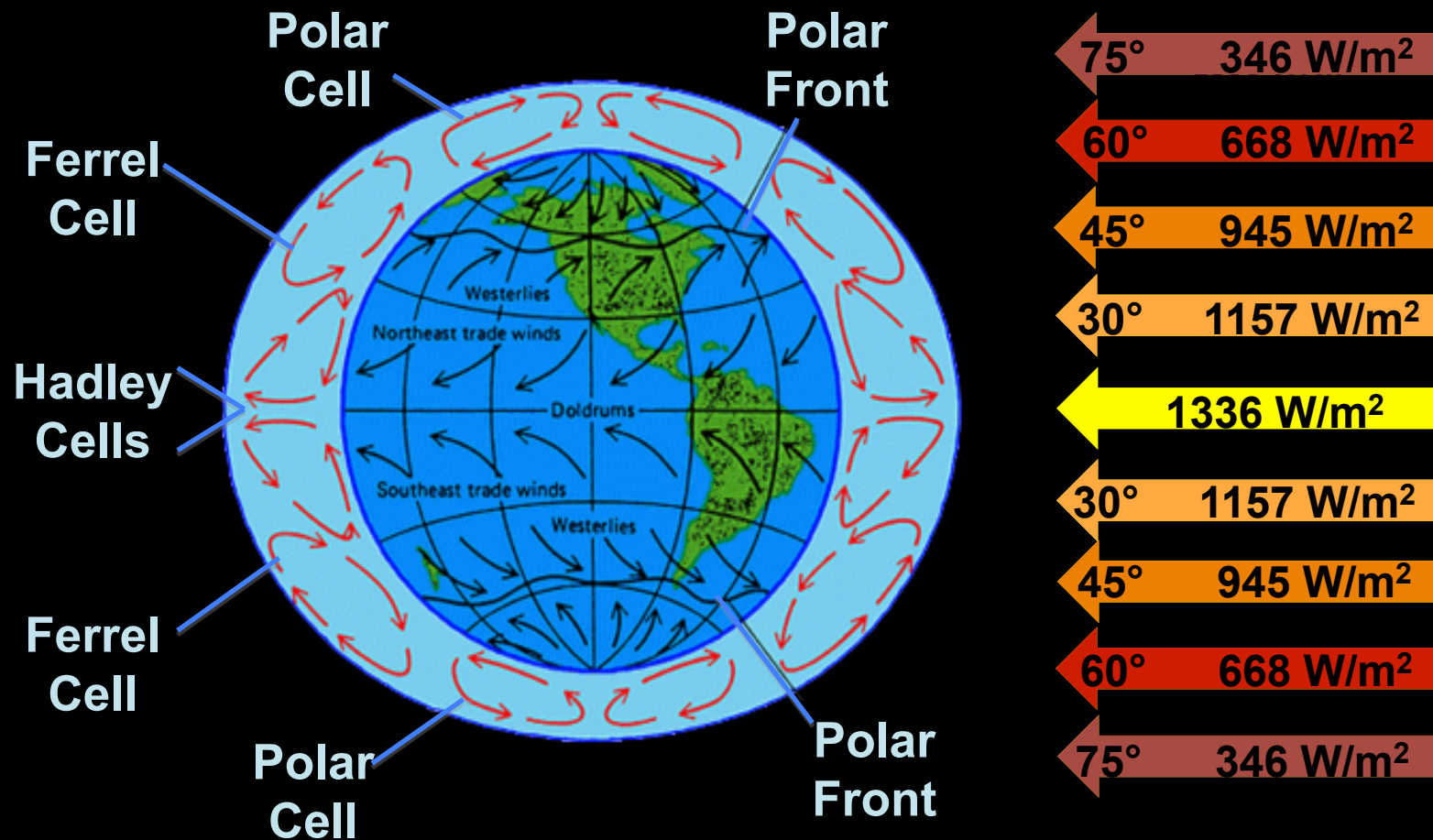
1. Solar Heating: Solar energy is not distributed evenly across the Earth's surface



1. Solar Heating: Different amounts of solar radiation received at different latitudes create heat imbalances that drive circulations



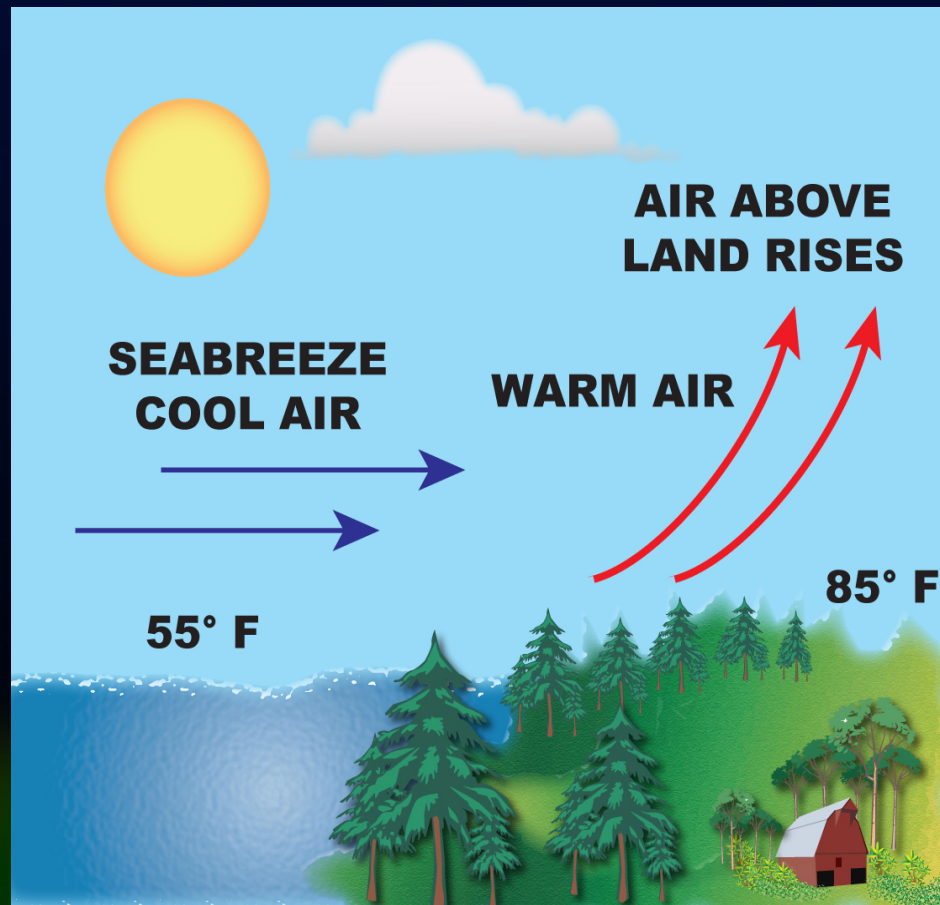
2. Earth's Rotation: Atmospheric circulations transport heat toward the colder poles. Earth's rotation deflects the winds into complicated three-dimensional patterns



2. Jupiter's Rotation: Other rotating planes also develop bands of easterly and westerly moving winds



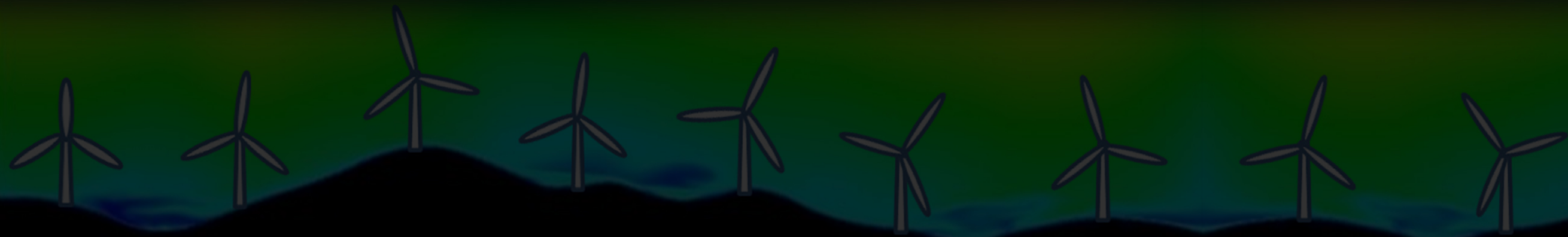
3. Surface characteristics: Temperature differences between land and sea drive local winds



- During a summer day the land temperature is greater than the ocean temperature
- Warmer air is less dense and will rise (it is buoyant) causing cooler, denser air from the colder ocean to flow inland

Can we capture the winds to make energy?

Break for First demo



What determines the power of a wind turbine?

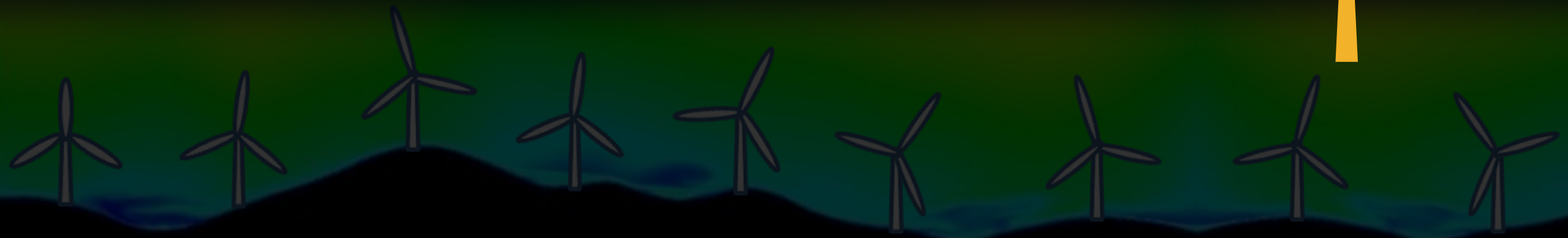
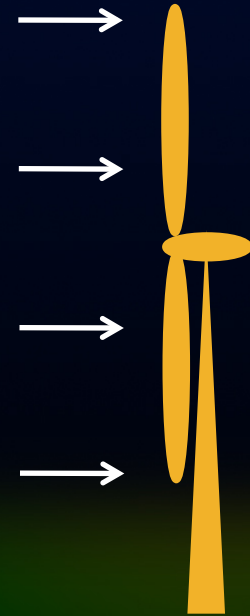
$$\text{Power} = \frac{1}{2} C_p \rho U^3 A$$



What determines the power of a wind turbine?

$$\text{Power} = \frac{1}{2} C_p \rho U^3 A$$

Wind
Speed



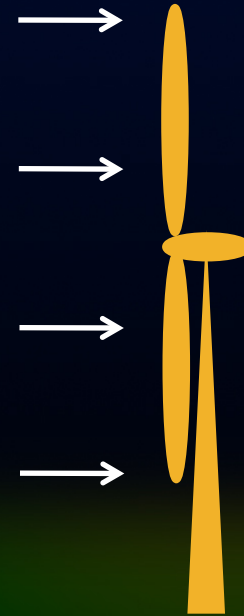
What determines the power of a wind turbine?

$$\text{Power} = \frac{1}{2} C_p \rho U^3 A$$

Pressure
 $P = dRT$
Gas Constant
Temperature

$$\frac{P}{RT} = d$$

Wind Speed
Air Density



Low d **WARM**
M

High d **COLD**

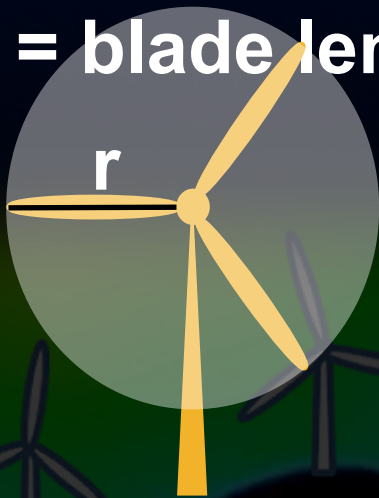


What determines the power of a wind turbine?

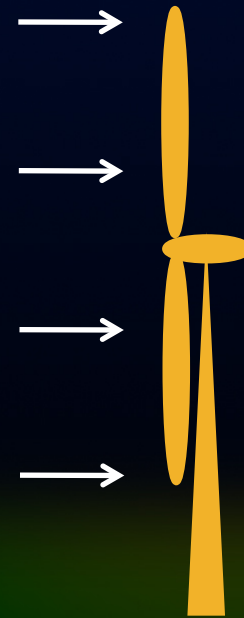
$$\text{Power} = \frac{1}{2} C_p \rho U^3 A$$

$$A = \pi r^2$$

r = radius of
disk
= blade length



Area of
Rotor
Wind
Speed
Air Density



Low ρ **WARM**

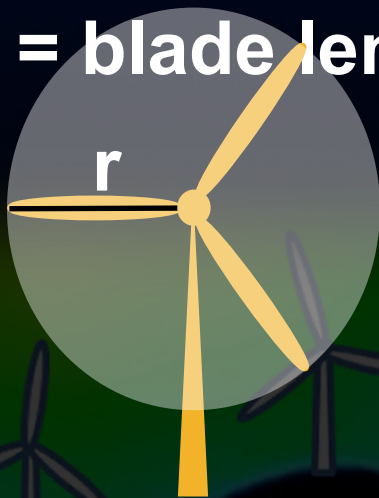
High ρ **COLD**

What determines the power of a wind turbine?

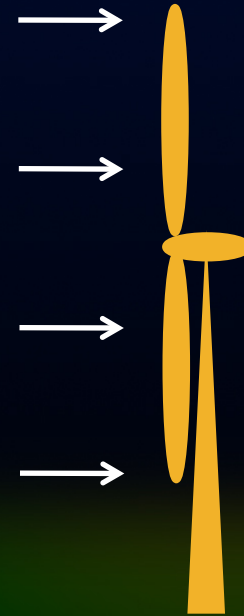
$$\text{Power} = \frac{1}{2} C_p \rho U^3 A$$

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r = radius of
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= blade length



Area of
Rotor
Wind
Speed
Air Density
Efficiency Factor



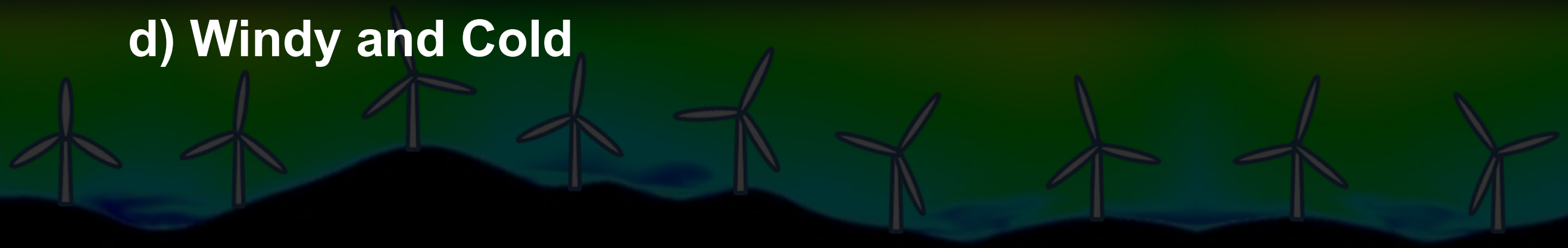
Low ρ **WARM**

High ρ **COLD**

Question 1: Which atmospheric conditions are best for wind energy?

- a) Calm and Hot
- b) Windy and Hot
- c) Calm and Cold
- d) Windy and Cold

$$\text{Power} = \frac{1}{2} C_p \rho U^3 A$$



Question 1: Which atmospheric conditions are best for wind energy?

a) Calm and Hot

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$$\text{Power} = \frac{1}{2} C_p \rho A U^3$$

$\frac{P}{RT} = d$



Question 1: Which atmospheric conditions are best for wind energy?

- a) Calm and Hot
- b) Windy and Hot
- c) Calm and Cold
- d) Windy and Cold**

$$\text{Power} = \frac{1}{2} C_p \rho U^3 A$$

$$\frac{P}{RT} = \rho$$



Question 2: How much more power can we produce if we double the wind speed?

a) 2 times

b) 4 times

c) 6 times

d) 8 times

$$\text{Power} = \frac{1}{2} C_p \rho U^3 A$$



Question 2: How much more power can we produce if we double the wind speed?

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$$\text{Power} = \frac{1}{2} C_p \rho U^3 A$$



Question 2: How much more power can we produce if we double the wind speed?

a) 2 times

b) 4 times

c) 6 times

d) 8 times

$$\text{Power} = \frac{1}{2} C_p \rho (2U)^3 A$$



Question 2: How much more power can we produce if we double the wind speed?

a) 2 times

b) 4 times

c) 6 times

d) 8 times

$$\begin{aligned}\text{Power} \\ &= \frac{1}{2} C_p \rho (2^3 U^3) A\end{aligned}$$



Question 2: How much more power can we produce if we double the wind speed?

a) 2 times

b) 4 times

c) 6 times

d) 8 times

$$\text{Power} = \frac{1}{2} C_p \rho A (8U^3)$$



Question 3: How much more power can we produce if we double the length of each blade?

a) 2 times

b) 4 times

c) 6 times

d) 8 times

$$\text{Power} = \frac{1}{2} C_p \rho U^3 A$$



Question 3: How much more power can we produce if we double the length of each blade?

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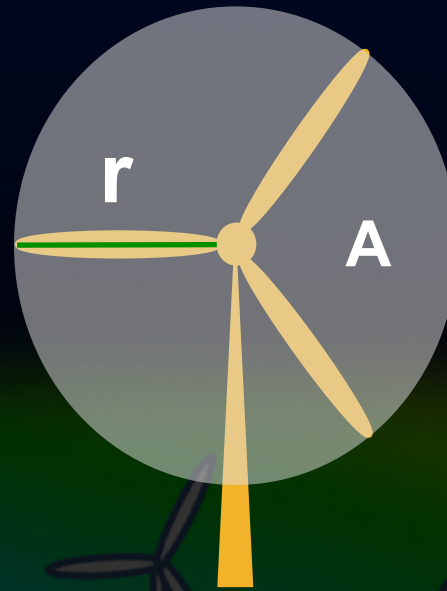
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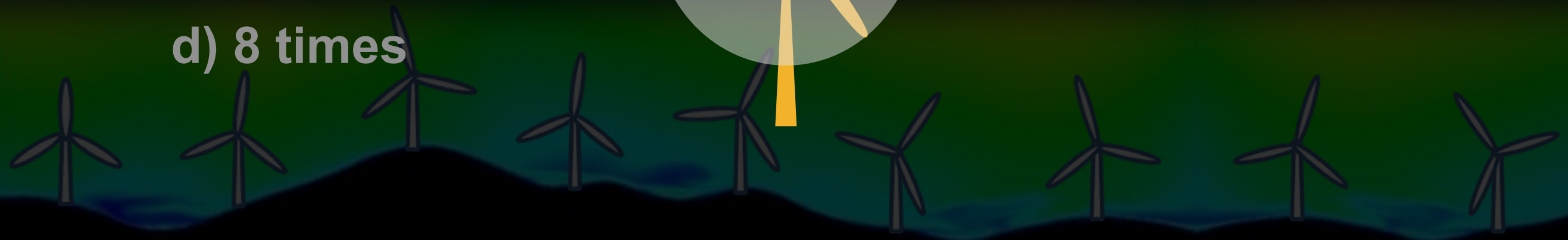
c) 6 times

d) 8 times

$$\text{Power} = \frac{1}{2} C_p \rho U^3 A$$



$$A = \pi r^2$$



Question 3: How much more power can we produce if we double the length of each blade?

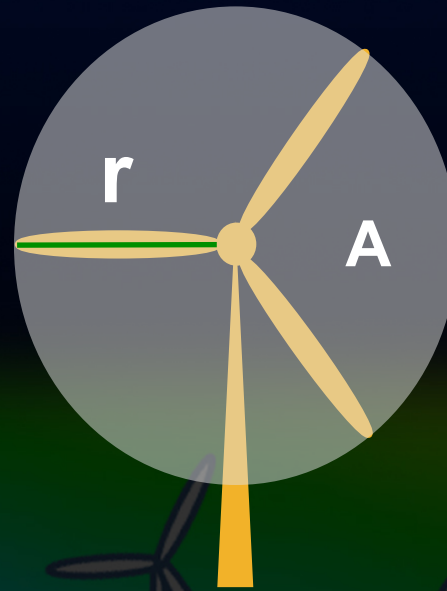
a) 2 times

b) 4 times

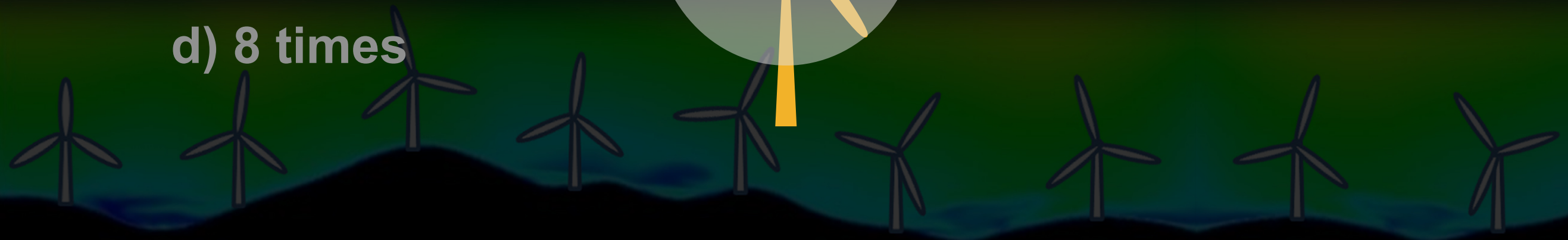
c) 6 times

d) 8 times

$$\text{Power} = \frac{1}{2} C_p \rho U^3 \pi r^2$$



$$A = \pi r^2$$



Question 3: How much more power can we produce if we double the length of each blade?

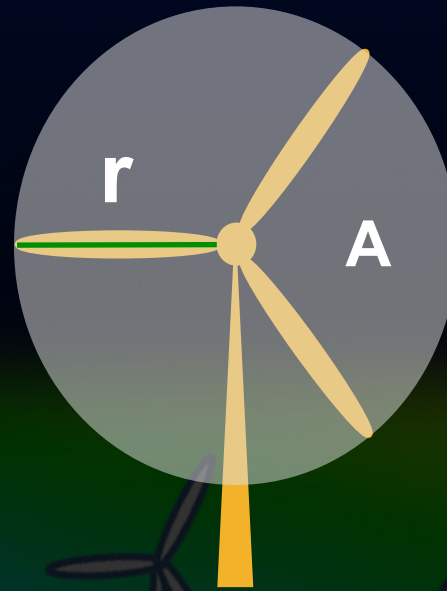
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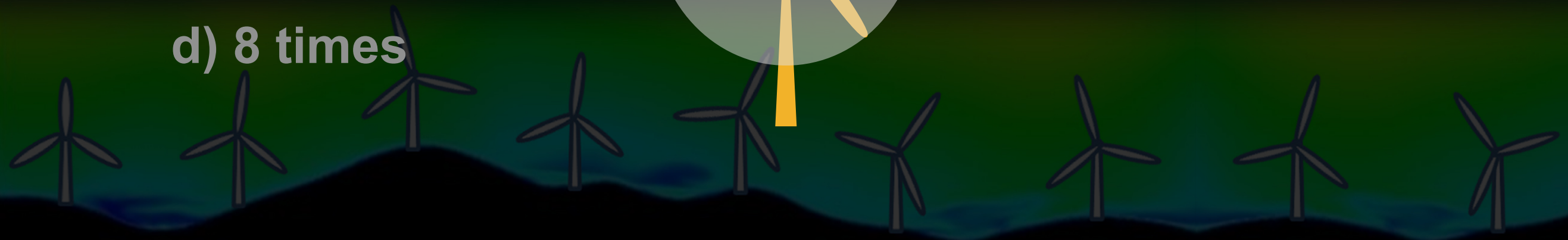
c) 6 times

d) 8 times

$$\text{Power} = \frac{1}{2} C_p \rho U^3 \pi (2r)^2$$



$$A = \pi r^2$$



Question 3: How much more power can we produce if we double the length of each blade?

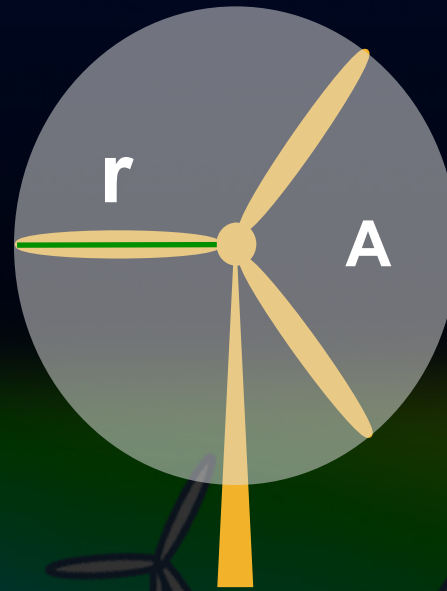
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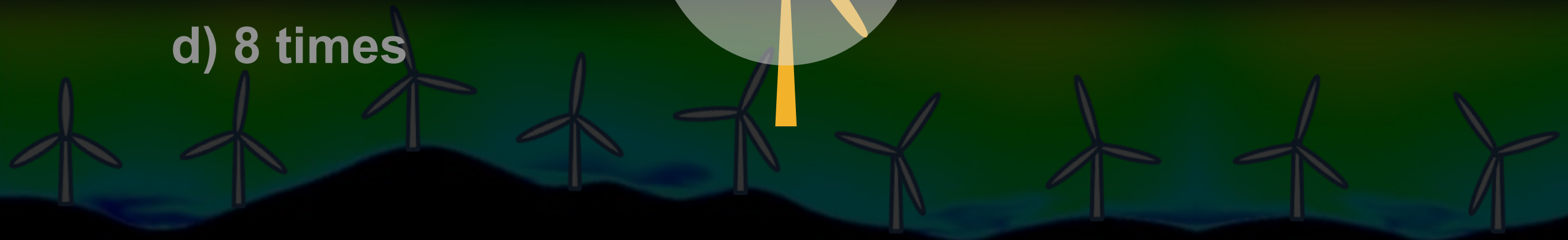
c) 6 times

d) 8 times

$$\text{Power} = \frac{1}{2} C_p \rho U^3 \pi (2^2 r^2)$$



$$A = \pi r^2$$



Question 3: How much more power can we produce if we double the length of each blade?

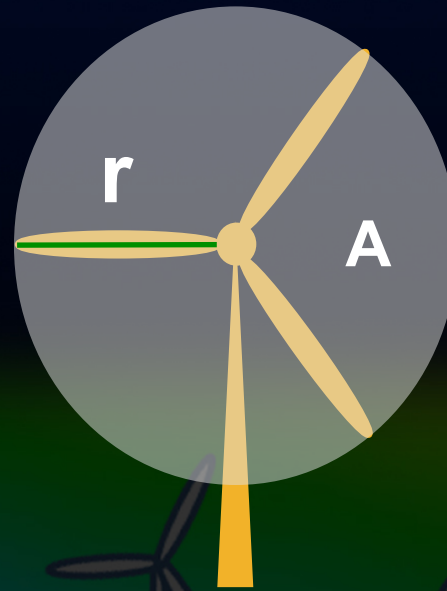
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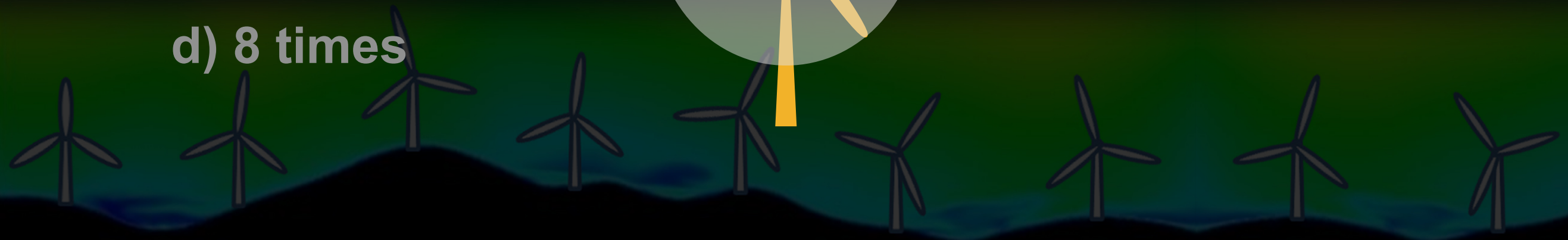
c) 6 times

d) 8 times

$$\text{Power} = \frac{1}{2} C_p \rho U^3 \pi (4r^2)$$



$$A = \pi r^2$$



Question 3: How much more power can we produce if we double the length of each blade?

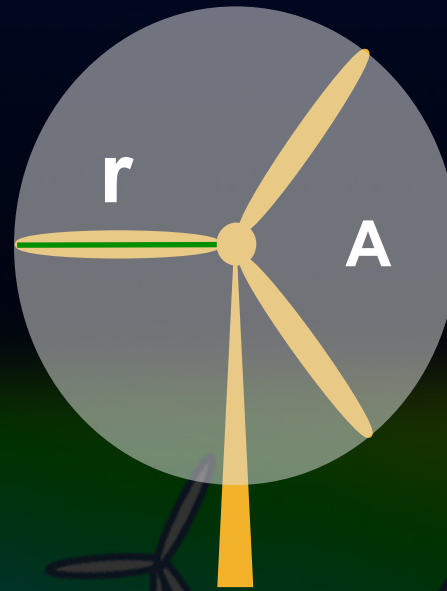
a) 2 times

b) 4 times

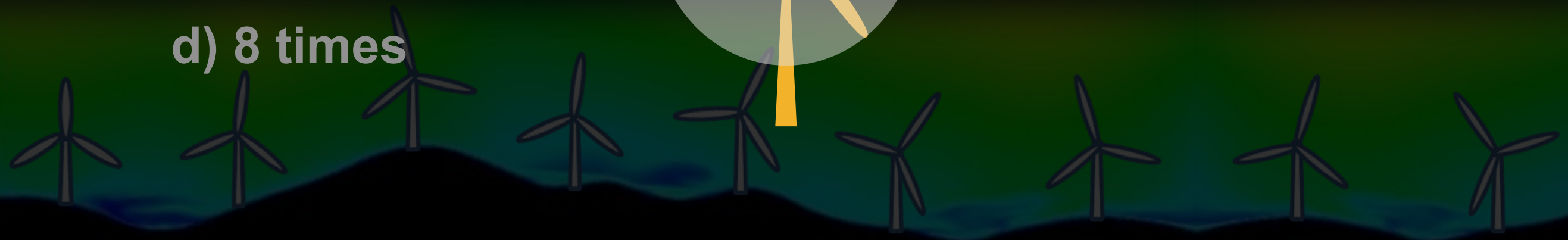
c) 6 times

d) 8 times

$$\text{Power} = \frac{1}{2} C_p \rho U^3 \pi (4r^2)$$



$$A = \pi r^2$$



Question 4: How much more power can we produce if we double both the wind speed and the length of each blade?

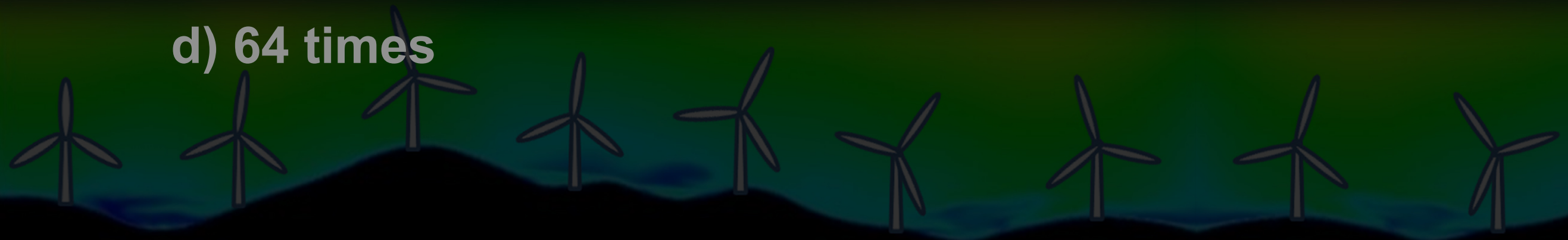
a) 8 times

b) 16 times

c) 32 times

d) 64 times

$$\text{Power} = \frac{1}{2} C_p \rho U^3 A$$



Question 4: How much more power can we produce if we double both the wind speed and the length of each blade?

a) 8 times

b) 16 times

c) 32 times

d) 64 times

$$\text{Power} = \frac{1}{2} C_p d U^3 A$$



Question 4: How much more power can we produce if we double both the wind speed and the length of each blade?

a) 8 times

b) 16 times

c) 32 times

d) 64 times

$$\text{Power} = \frac{1}{2} C_p \rho U^3 \pi r^2$$



Question 4: How much more power can we produce if we double both the wind speed and the length of each blade?

a) 8 times

b) 16 times

c) 32 times

d) 64 times

Power

$$= \frac{1}{2} C_p \rho (2U)^3 \pi (2r)^2$$



Question 4: How much more power can we produce if we double both the wind speed and the length of each blade?

a) 8 times

b) 16 times

c) 32 times

d) 64 times

$$\text{Power} = \frac{1}{2} C_p d (2^3 U^3) \pi (2^2 r^2)$$



Question 4: How much more power can we produce if we double both the wind speed and the length of each blade?

a) 8 times

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d) 64 times

$$\text{Power} = \frac{1}{2} C_p d (8U^3) \pi (4r^2)$$



Question 4: How much more power can we produce if we double both the wind speed and the length of each blade?

a) 8 times

b) 16 times

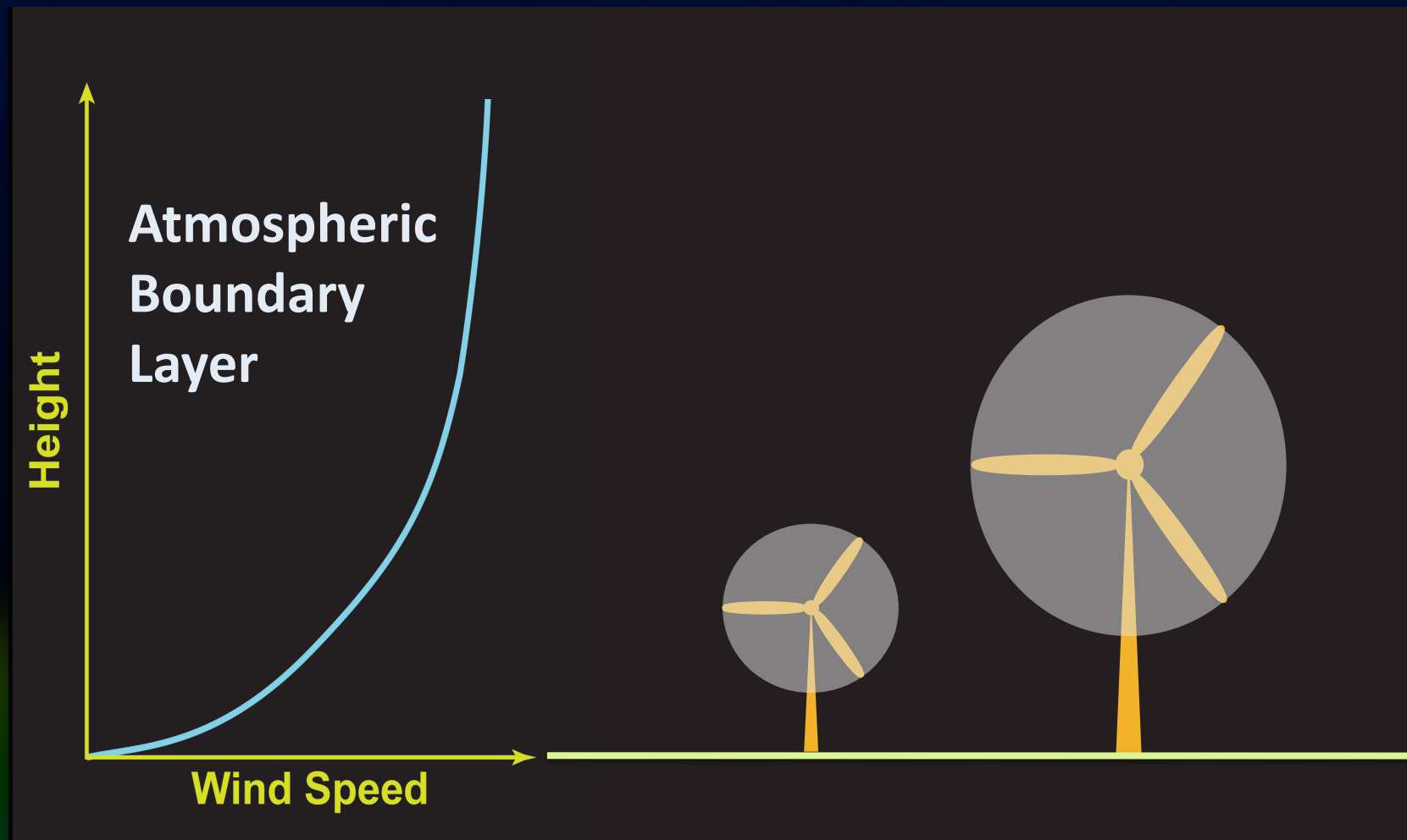
c) 32 times

d) 64 times

$$\text{Power} = \frac{1}{2} C_p d (8U)^3 \pi (4r)^2$$



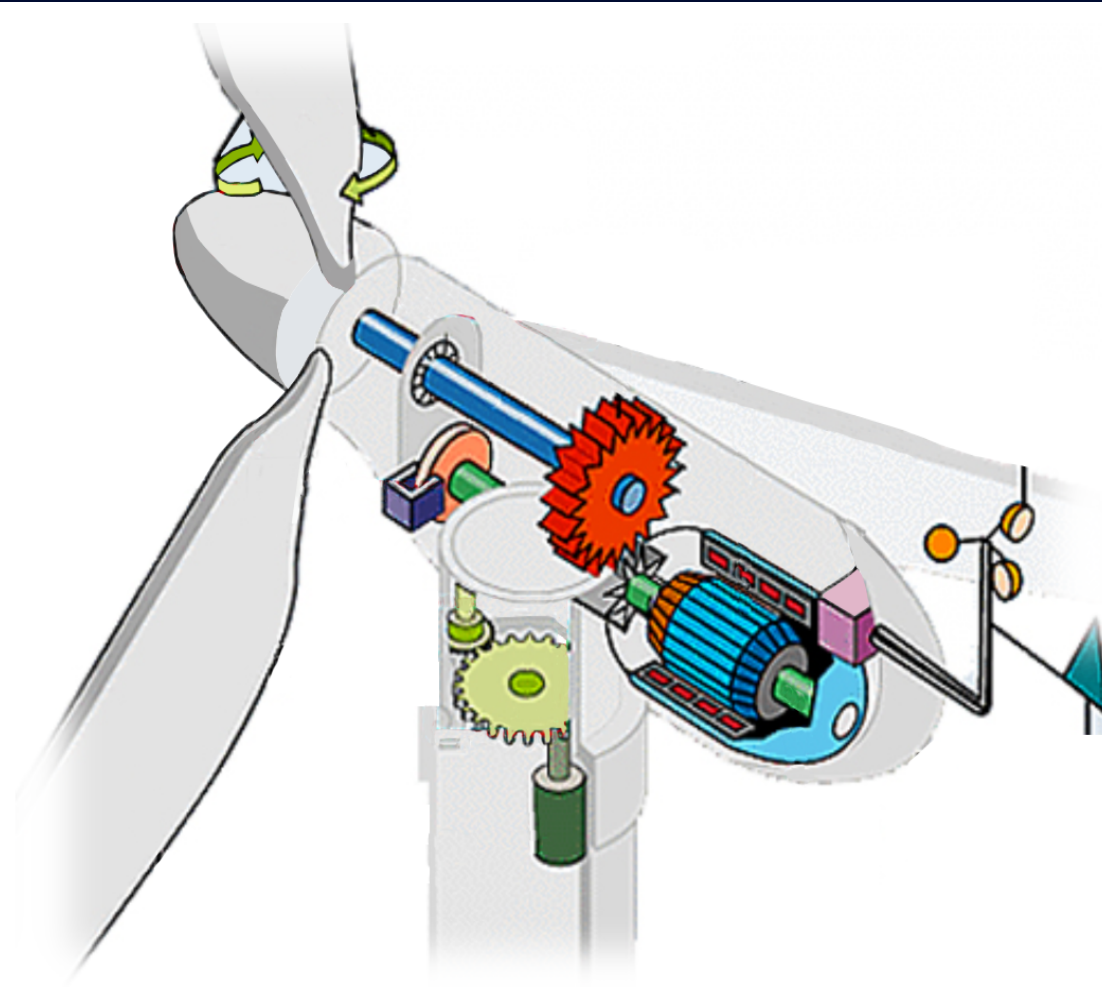
Why are modern wind turbines so tall?



Wind turbines blades are uniquely shaped

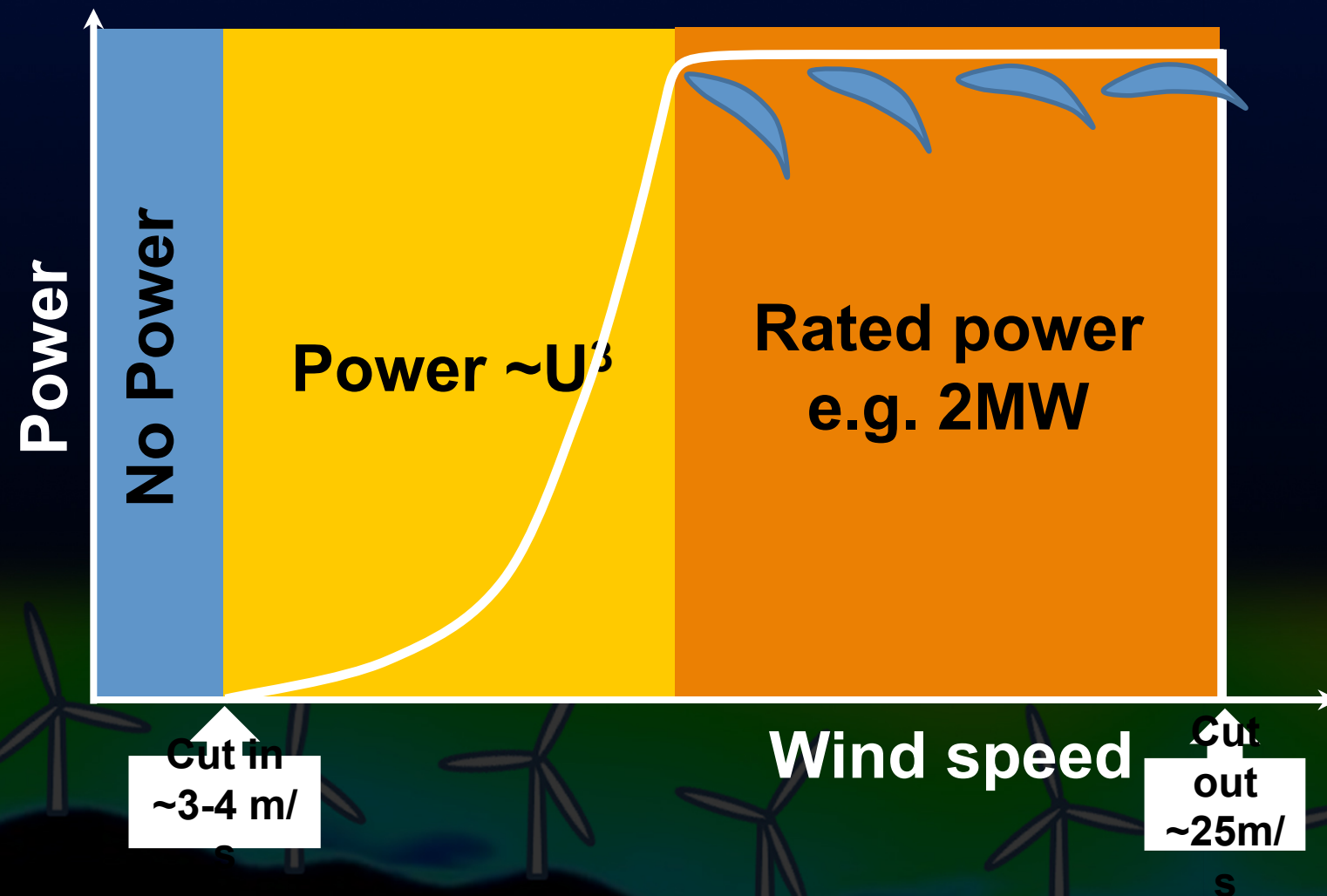


Wind turbines have gearboxes, generators and other control mechanisms in the nacelle

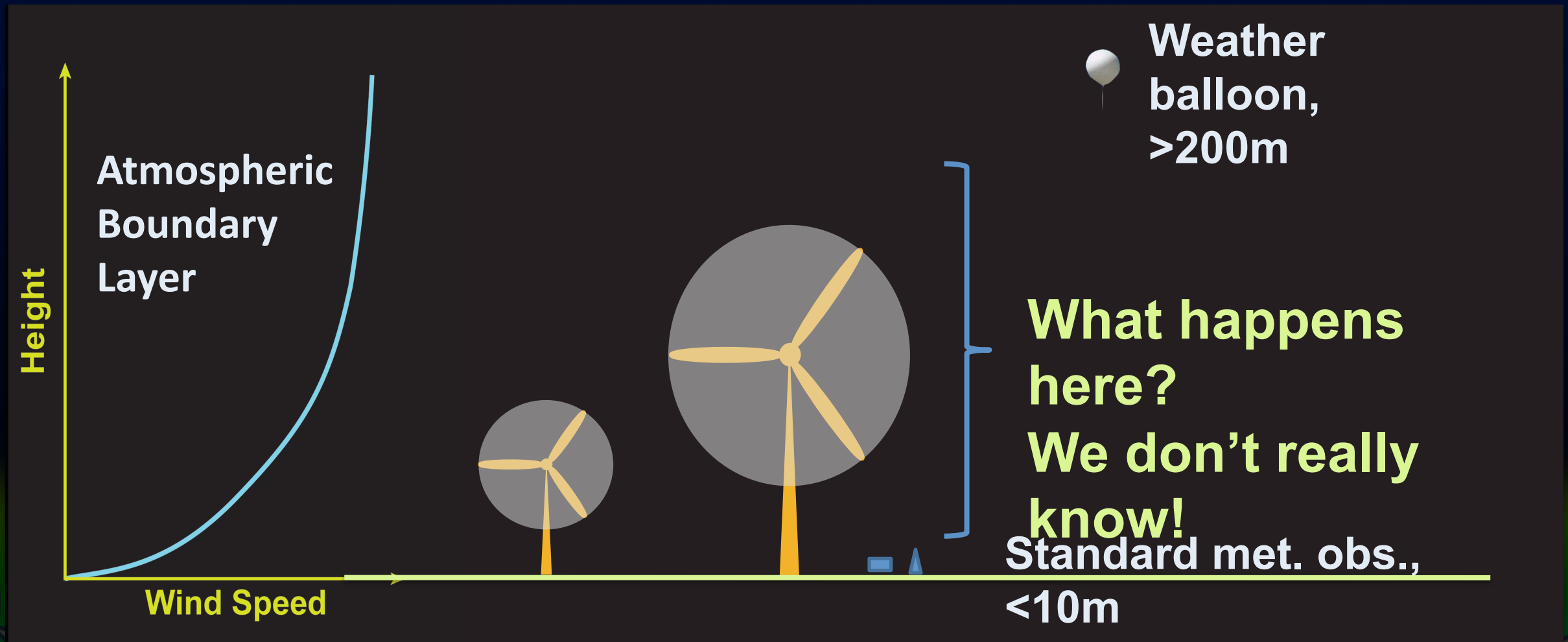


- **Generator** – blades turn the generator which produces energy
- **“Yaw”** – positions the rotor into the wind
- **“Pitch”** – controls the angles of the blades

Wind turbines produce power according to a power curve



The flow at wind turbine heights is not well understood



Demo 2: How do scientists measure the wind far above the ground?



We use a sonic anemometer which measures both wind speed and direction at 10 times a second! That is fast enough to measure turbulence in the wind.

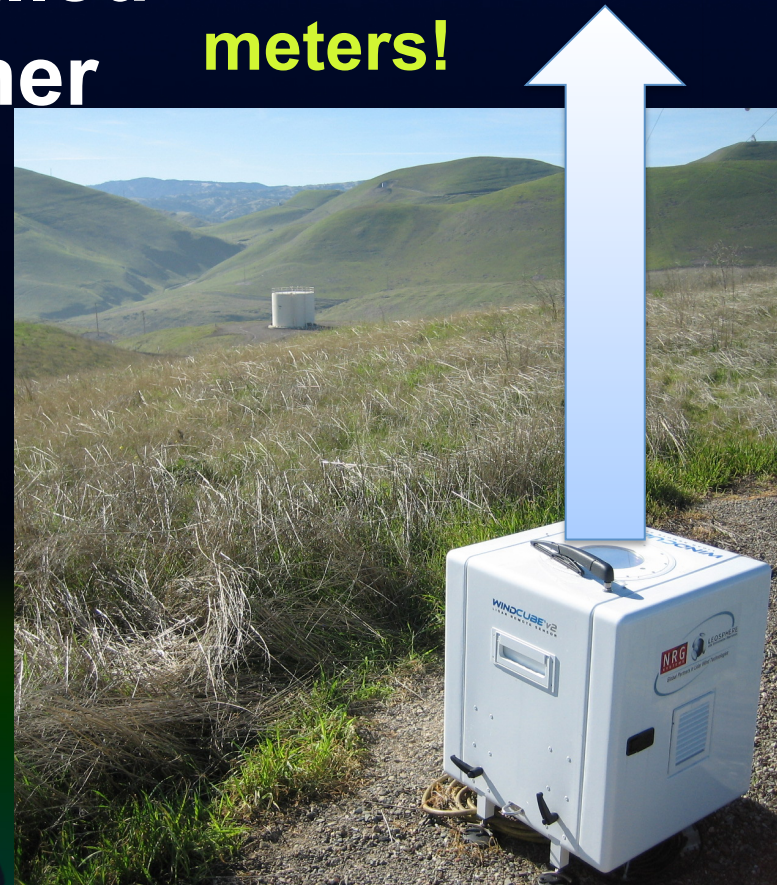
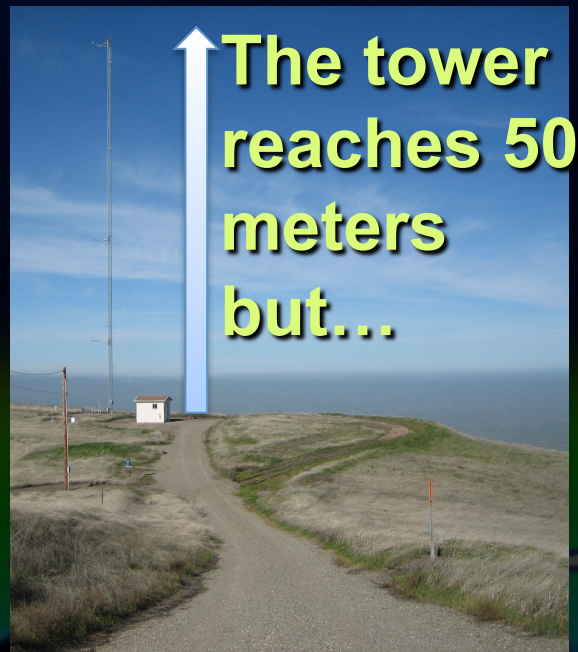
LET'S COLLECT SOME DATA!



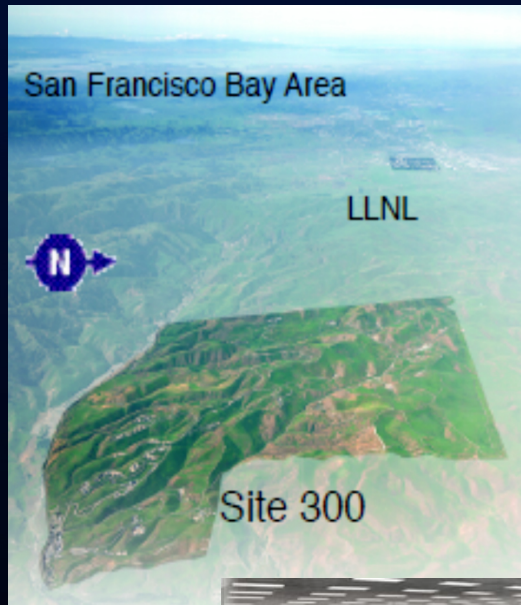
Other Instruments Used

We also use a more sophisticated instrument called a LIDAR which reaches higher winds

the LIDAR reaches 200 meters!



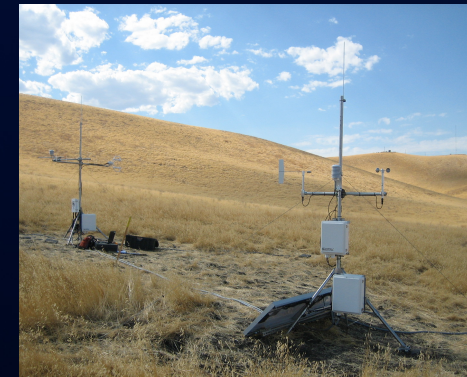
At LLNL, we are taking atmospheric measurements and modeling wind to understand wind flow over complex terrain



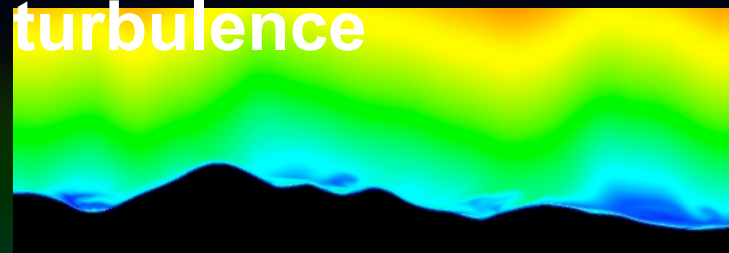
Supercomputers



**Wind speed,
direction, and
turbulence**

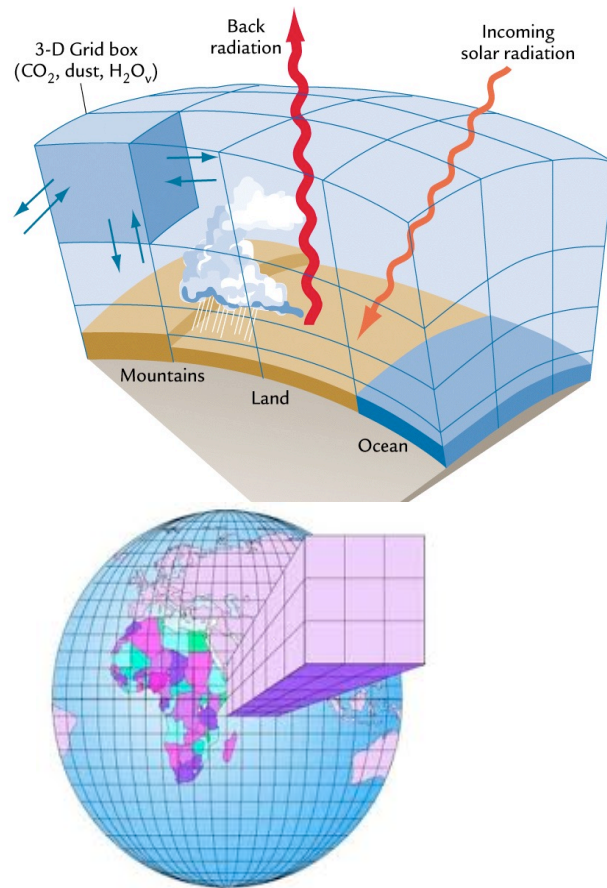


**Surface
energy
exchange**



**Atmospheric
modeling**

Models: Observations coupled with models can tell us where the good wind resources are.



- Conservation of momentum

$$\frac{\partial \vec{V}}{\partial t} = -(\vec{V} \cdot \nabla) \vec{V} - \frac{1}{\rho} \nabla p - \vec{g} - 2\vec{\Omega} \times \vec{V} + \nabla \cdot (k_m \nabla \vec{V}) - \vec{F}_d$$

- Conservation of energy

$$\rho c_{\vec{V}} \frac{\partial T}{\partial t} = -\rho c_{\vec{V}} (\vec{V} \cdot \nabla) T - \nabla \cdot \vec{R} + \nabla \cdot (k_T \nabla T) + C + S$$

- Conservation of mass

$$\frac{\partial \rho}{\partial t} = -(\vec{V} \cdot \nabla) \rho - \rho (\nabla \cdot \vec{V})$$

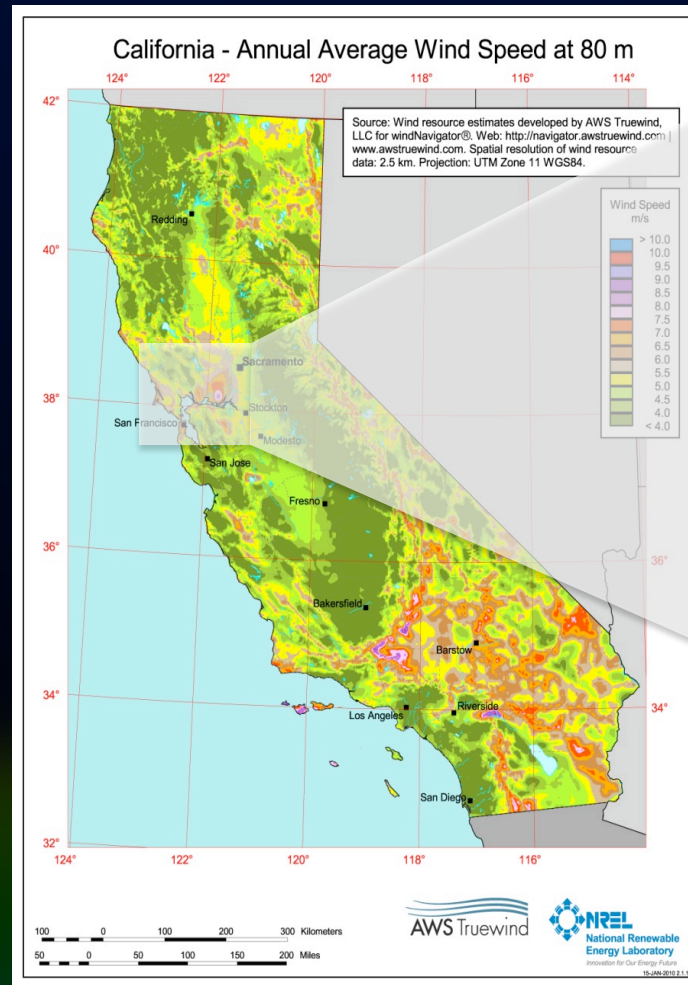
- Conservation of H_2O (vapor, liquid, solid)

$$\frac{\partial q}{\partial t} = -(\vec{V} \cdot \nabla) q + \nabla \cdot (k_q \nabla q) + S_q + E$$

- Equation of state

$$p = \rho R_d T$$

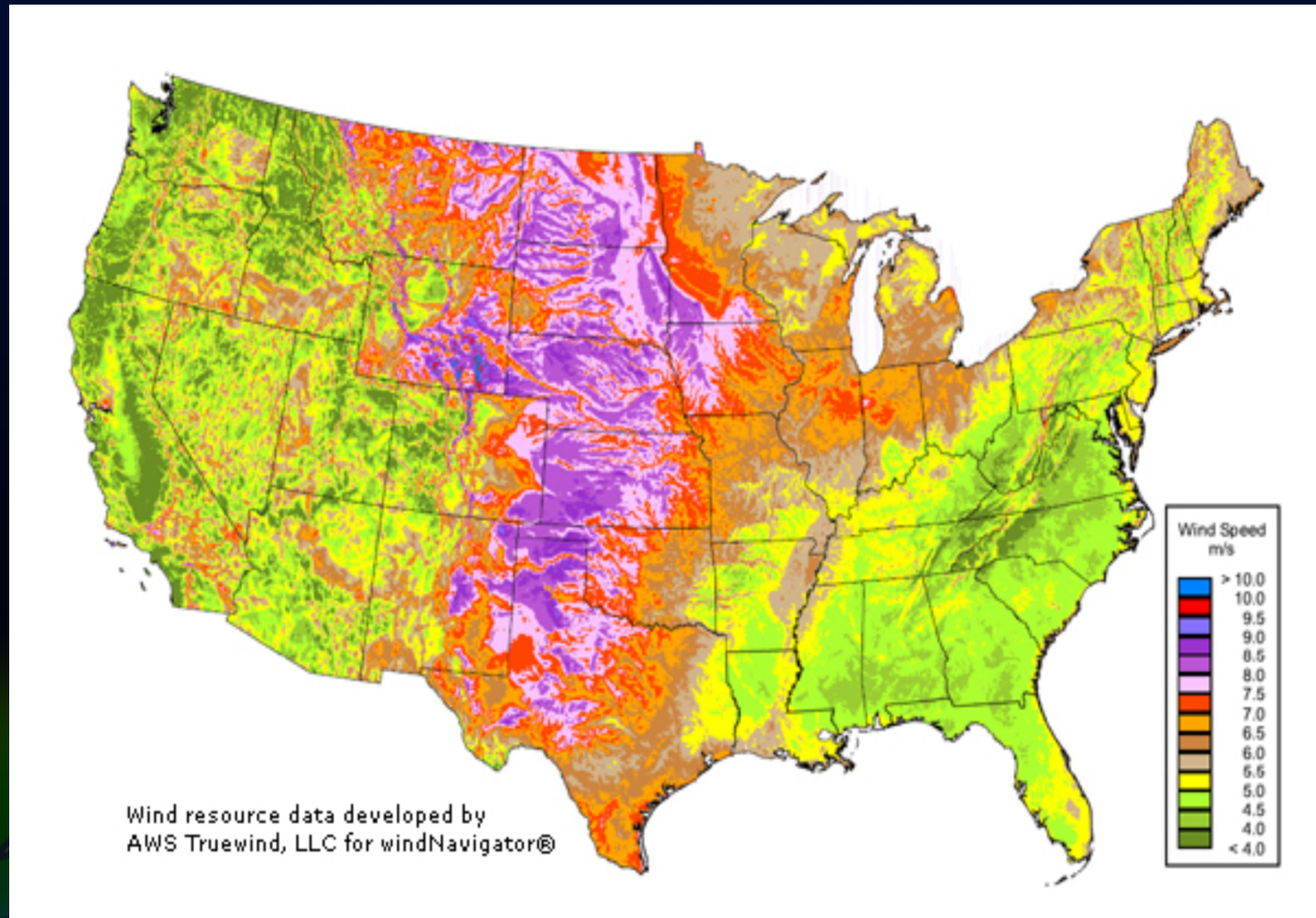
Where is it windiest in California?



San Francisco



How do the winds in California compare to the rest of the US?



Challenges

- **Transmission and storage**
- **Measurement and forecasting**
- **Efficiency and engineering of wind turbines**
- **Balancing with other renewable sources**
- **Diverse, innovative, educated people (you!)**



Careers in Wind



- Meteorologist
- Computer modeler
- Engineer
- Field technician

What Did We Learn?

1. Why the wind blows
2. How modern wind turbines harness the wind
3. The roles of science and engineering in improving wind energy capture
4. The challenges that remain for you to solve

